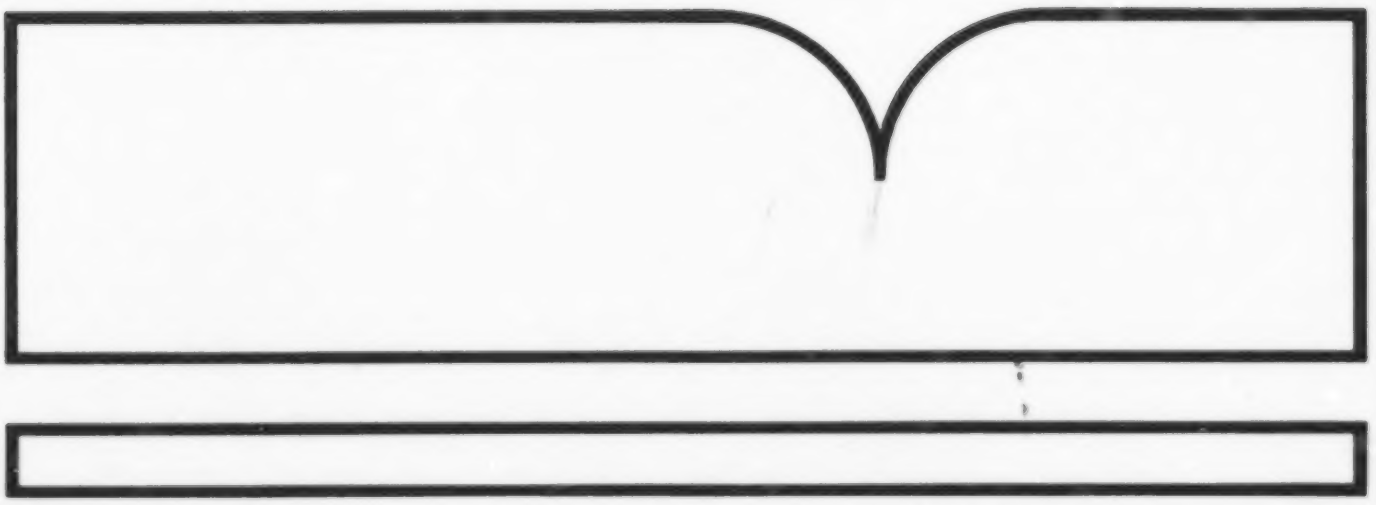
PB82-207879

Yolk Utilization and Growth to Yolk-Sac Absorption in Summer Flounder ('Paralichthys dentatus') Larvae at Constant and Cyclic Temperatures

(U.S.) Environmental Research Lab.
Narragansett, RI

1981



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1. REPORT NO.	2.	3.
EPA-600/J-81-185	Journal Article	PB82-207879

4. TITLE AND SUBTITLE	5. REPORT DATE
Yolk Utilization and Growth to YolkSac Absorption in Summer Flounder (Paralichthys dentatus) Sarvae at Constant and Cyclic Temperatures.	xxxxxx May 1982
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)	8. PERFORMING ORGANIZATION REPORT NO.
D.M. Johns, W.H. Howell, and G. Klein-MacPhee	ERLN-195 EPA 600/J-81-185
9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. PROGRAM ELEMENT NO.
U.S.EPA, ERL, Narragansett South Ferry Road Narragansett, RI 02882	ACUL1A/CCUL1A
	11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS	13. TYPE OF REPORT AND PERIOD COVERED
	Journal Article
	14. SPONSORING AGENCY CODE
	EPA/600/05

15. SUPPLEMENTARY NOTES

Published in: Marine Biology, Vol.63,pp.301-308,(1981)

16. ABSTRACT

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17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS *(This Report)*	21. NO. OF PAGES
Distribution Unlimited	Unclassified	10
	20. SECURITY CLASS *(This page)*	22. PRICE
	Unclassified	

EPA Form 2220-1 (9-73)

Marine Biology 63, 301–308 (1981)

MARINE BIOLOGY

EPA-600/J-81-185
Journal Article

Yolk Utilization and Growth to Yolk-Sac Absorption in Summer Flounder *(Paralichthys dentatus)* Larvae at Constant and Cyclic Temperatures*

D. M. Johns[1], W. H. Howell[1,2] and G. Klein-MacPhee[1]

[1] United States Environmental Protection Agency, Environmental Research Laboratory; South Ferry Road, Narragansett, Rhode Island 02882, USA

[2] Department of Zoology, University of New Hampshire; Durham, New Hampshire 03824, USA

Abstract

Rates of development, growth and yolk conversion efficiency were determined in larvae of the summer flounder *Paralichtys dentatus* at constant temperatures of 21°, 16°, 12° and 5°C and in temperature cycles of 21°-16°, 16°-11°, and 11°-5°C. In constant incubation temperatures, development rate increased with increasing temperature. Larvae reared in the cyclic temperature regimes exhibited development rates intermediate to those at the temperature extremes of the cycle. All larvae reared at 5°C and in the 11°-5°C cycle regime died prior to total yolk-sac absorption. Although development rates were temperature dependent, no significant differences in notochord length ash-free dry weight or yolk utilization efficiency were found at the time of total yolk-sac absorption. The similarity in growth and yolk utilization efficiency for larvae reared under these various temperature regimes suggests that the physiological mechanisms involved are able to compensate for temperature changes encountered in nature.

Introduction

Size at the time of total yolk-sac absorption, when fish larvae switch from an endogenous food source (yolk) to exogenous feeding, may be an ecologically important variable in determining year-class strength. Greater larval size during this transitional period may increase the larva's ability to compete for available food resources and avoid predation (Blaxter and Hempel, 1963; Braum, 1967; Blaxter, 1969). Ryland (1963) found for plaice larvae that a 10% increase in larval size corresponded to a 10 to 25% increase in swimming speed. Increases of this magnitude would have a positive effect on the survival potential of larvae. Larger larvae, in addition to having better foraging and predator avoidance potential, may also have a greater ability to resist starvation (Blaxter and Hempel, 1963). Hence a factor that affects larval size during yolk-sac absorption could have a significant effect on chances of survival and year-class strength.

Temperature is one such factor; it is thought to play a dominant role in the efficiency with which yolk is converted to body tissue (Blaxter, 1969; Brett, 1970). Generally, highest yolk utilization efficiencies occur in an intermediate range of temperatures within the zone of tolerance. At temperatures above and below this range, metabolic requirements proportionally are greater than those contributing to tissue production, resulting in smaller larvae (Hayes and Pelluet, 1945; Blaxter, 1969). Marr (1966) determined yolk conversion efficiencies for trout (*Salmo trutta*) larvae incubated at temperatures between 4° and 12°C and found the peak efficiency to be at 10°C. At 4°C, 57% of the yolk was converted to tissue while larvae maintained at 10°C converted approximately 81% of the yolk to tissue. Similar unimodal temperature-efficiency relationships have been reported in other fish species (Hayes and Pelluet, 1945; Ryland and Nichols, 1976; Laurence, 1973). Contrasting these findings however, are the results of several studies in which yolk tissue conversion efficiencies and larval size at yolk-sac absorption were found to be independent of temperature. May (1975) reports yolk conversion efficiencies within the narrow range of 71.4 to 74.3% in *Bairdiella icistia* larvae incubated at temperatures covering the entire range of thermal tolerance. Johns and Howell (1980) found no significant difference in either larval size or ash-free dry weight among larvae of the summer flounder *Paralichthys dentatus* maintained at 21° and 16°C. Howell (1980) also reports similar findings for yellowtail flounder (*Limanda ferruginea*) larvae incubated at temperatures of 8°, 10° and 12°C.

* Contribution No. 195 from EPA, Environmental Research Laboratory, Narragansett, Rhode Island 02882, USA

0025-3162/81/0063/0301/$01.60

Such temperature independence in yolk conversion efficiencies is possible when physiological compensation for temperature exists, resulting in an equilibrium between the rate at which yolk is used for metabolic requirements and the rate at which it is converted to tissue (Blaxter and Hempel, 1966; Johns and Howell, 1980).

The present study used both constant and cyclic temperature regimes to examine further the apparent thermal independence of yolk utilization and size at yolk-sac absorption in larvae of the summer flounder *Paralichthys dentatus*. The temperature regimes used encompassed the zone of thermal tolerance of summer flounder larvae in northeastern USA coastal waters (Smith, 1973).

Materials and Methods

Brood stock adult summer flounder *Paralichthys dentatus* were collected by otter trawl from the West Passage of Narragansett Bay, Rhode Island, USA, between June and September, 1979. Adults were maintained in the laboratory in 2700-l tanks supplied with unfiltered sea water. As in our previous work (Johns and Howell, 1980) ripening in both sexes was induced by intramuscular injection 4–5 times weekly using 1.0 mg carp pituitary dissolved in Ringer's solution per kilogram fish weight, following the method of Smigielski (1975). Eggs were stripped into plastic pans and fertilized with milt in seawater. Fertilized eggs were placed in 6-l plastic pans of sea water at ambient temperature (15 ° to 18 °C). The pans were placed in water baths where the newly-fertilized eggs slowly came to the desired temperature (approximately 240 min).

The developing embryos were cultured at constant temperatures (CON) of 5 °, 11 °, 16 ° and 21 °C, and daily cyclic temperatures (CYC) of either 5 ° to 11 °, 11 ° to 16 °, or 16 ° to 21 °C. All embryos were subjected to a 12 h L : 12 h D light : dark cycle. The warmer portion of the temperature cycle coincided with the light portion of the photoperiod. The pattern of water temperature change in the cyclic regimes was a square wave with the upper and lower portions of the cycle being held constant for 10 h. Roughly 2 h was needed for water temperature to change between the two extremes of the cycle. The mean temperature for each daily cycle approximated the arithmetic mean of the cycle (i.e., 5 ° to 11 °C CYC had a mean water temperature of 8 °C, etc.).

The constant test temperatures were maintained within ± 0.75 C° of the nominal value using Instant Ocean* aquaria equipped with a temperature-regulating circulation bath. Experiments with the cyclic temperature regimes were conducted in a Sherer* controlled-environment chamber.

Space limitations did not allow examination of all thermal regimes at once. Instead, one thermal regime couplet (e.g. the 11 ° and 21 °C CON and 11 ° to 21 °C CYC) was run at one time. The design allowed each experimental temperature to be duplicated at least once. The design did not allow for culture of embryos and yolk-sac larvae from the eggs of the same female in all thermal regimes. Therefore, a one-way analysis of variance (Snedecor and Cochran, 1967) was used to determine if there were significant differences in the size of unfertilized ova used in the various experiments. If a significant difference was found ($P \leq 0.05$), data obtained from those eggs were not used in the analyses.

The energy budget of an organism with an endogenous source of energy can be defined by the following equation:

$$C = P + R + U, \quad (1)$$

where C is the yolk energy consumed, P the portion of energy used for growth, R the portion used for metabolism, and U the portion lost through excretion. For these experiments, daily energy budgets were calculated by the dry weight method (Toetz, 1966; Laurence, 1969). In general, energy consumed (C) and converted to tissue growth (P) were determined from calculations of daily changes in yolk and tissue weights, which then were multiplied by their respective Joule equivalents to yield daily values of energy used or converted to tissue. The difference (C-P) is the energetic cost of metabolism (R) as well as energy lost through excretion (U). Values of R and U were not directly determined and were considered together as energy lost during development.

All laboratory measurements needed to calculate the daily energy budgets, including dry weight and ash-free weight determinations, yolk volume determinations, and notochord lengths were determined as reported elsewhere (Johns and Howell, 1980) for summer flounder larvae.

Results

The volumes of unfertilized ova were found to be variable, those obtained from fish number 4 being significantly larger ($P \leq 0.05$) than those from the other fish used (Table 1). Since significant differences in the initial volume of the egg could mask dissimilarities in growth and energy utilization that were due to

Table 1. *Paralichthys dentatus*. Egg volume (mean ± SD) of unfertilized ova from the five fish used in this study. Means having the same grouping letter are not significantly different ($P > 0.05$). (n): sample size

Fish No.	Egg Volume (mm^3)	(n)	Grouping
1	0.473 ± 0.029	25	B
2	0.463 ± 0.025	26	B
3	0.477 ± 0.022	23	B
4	0.503 ± 0.038	26	A
5	0.468 ± 0.027	25	B

* Reference to tradenames does not imply endorsement by the United States Environmental Protection Agency

Table 2. *Paralichthys dentatus*. Combined data (mean ± SD) on unfertilized ova. Calculated values do not have a sample size determination. (*n*): sample size; Dashes: no data

Material	Diameter (mm)	(*n*)	Dry wt. (μg)	(*n*)	% Ash	(*n*)	Volume (mm^3)	(*n*)
Ova	0.98 ± 0.08	99	36.70 ± 1.96	10	10.1 ± 0.8	10	0.471 ± 0.261	99
Yolk within Ova	0.93 ± 0.05	99	31.72		9.1		0.447 ± 0.280	99
Chorion	–		4.98 ± 0.25[a]		12.8 ± 8.3[a]		–	

[a] Value from previous study (Johns and Howell, 1980)

Table 3. *Paralichthys dentatus*. Development times for embryos and yolk-sac larvae maintained in constant and cyclic thermal regimes

Temp (°C)	Time Fertilization to hatch (h)	Time Hatch to yolk-sac absorption (h)	Total time (h)
21	54	67	121
21–16	72	72	144
16	77	105	182
16–11	141	96	240
11	150	137	287
11–5	a		
5	217	a	

[a] 100% mortality prior to this stage of development

environmental conditions, data collected from fish number 4 were not included in the following analyses.

The mean diameter for the eggs from the remaining fish (all data combined) was 0.98 mm (Table 2). Yolk within the ovum occupied approximately 95% of the egg volume and accounted for 86% of the dry weight.

As development progressed, the yolk reserves decreased, owing to growth and metabolic requirements of the embryo. Rate of development was dependent on temperature, with development rate increasing as temperature increased (Table 3). Development times for larvae in the cyclic temperatures were intermediate to those in the comparative constant temperatures forming the limits of the cyclic temperature tests.

The effect of constant incubation temperatures on yolk utilization rate is summarized in Table 4. Yolk

Table 4. *Paralichthys dentatus*. Changes in mean yolk volume and yolk ash-free dry weight (± 1 SD) for larvae reared at various constant temperatures. (*n*): sample size; *: yolk reserves exhausted, no further measurements taken

Temp (°C)	Post-hatch time (h)	Yolk volume (mm^3)	(*n*)	Yolk ash-free dry wt (μg)	(*n*)	% Loss from initial volume of 0.447 mm^3
21	0	0.112 ± 0.049	46	8.37 ± 3.18	10	74.9
16	0	0.152 ± 0.053	49	11.38 ± 3.92	10	65.9
11	0	0.162 ± 0.071	51	12.13 ± 5.32	10	63.7
5[a]	0	–		–		–
21	24	0.019 ± 0.008	49	1.43 ± 0.62	8	95.7
16	24	0.065 ± 0.022	48	4.85 ± 1.50	10	85.4
11	24	0.074 ± 0.047	56	5.56 ± 1.65	10	83.4
21	48	0.006 ± 0.002	45	0.40 ± 0.14	10	98.8
16	48	0.017 ± 0.009	49	1.23 ± 0.68	10	96.3
11	48	0.031 ± 0.012	63	2.31 ± 0.82	10	93.1
21	67	0.000 ± 0.000	50	0.00 ± 0.00	7	100.0
16	72	0.006 ± 0.003	51	0.42 ± 0.19	10	98.7
11	72	0.017 ± 0.007	65	1.28 ± 0.49	10	96.1
21	*					
16	105	0.000 ± 0.000	42	0.00 ± 0.00	10	100.0
11	96	0.009 ± 0.005	67	0.67 ± 0.30	10	98.0
21						
16	*					
11	120	0.003 ± 0.002	51	0.23 ± 0.09	10	99.3
21						
16						
11	137	0.000 ± 0.000	50	0.00 ± 0.00	10	100.0

[a] Abnormal yolk-sac not measureable

Table 5. *Paralichthys dentatus*. Changes in mean yolk volume and yolk ash-free dry weight (± 1 SD) for larvae reared at various cyclic temperatures, (*n*): sample size; *: yolk reserves exhausted, no further measurements taken

Temp cycle (°C)	Post-hatch time (h)	Yolk volume (mm^3)	(*n*)	Yolk ash-free dry wt (μg)	(*n*)	% Loss from initial volume of 0.447 mm^3
21-16	0	0.183 ± 0.073	50	13.68 ± 5.48	10	59.0
16-11	0	0.147 ± 0.043	48	10.98 ± 3.17	10	67.1
11-5	a					
21-16	24	0.096 ± 0.040	43	7.20 ± 2.98	10	78.4
16-11	24	0.074 ± 0.022	49	5.56 ± 1.61	10	83.3
21-16	48	0.013 ± 0.007	46	0.94 ± 0.45	9	97.2
16-11	48	0.024 ± 0.008	50	1.76 ± 0.63	10	94.7
21-16	72	0.000 ± 0.000	50	0.00 ± 0.00	10	100.0
16-11	72	0.015 ± 0.003	45	1.15 ± 0.26	10	96.5
21-16	*					
16-11	96	0.000 ± 0.000	50	0.00 ± 0.00	8	100.0

[a] 100% mortality prior to hatching

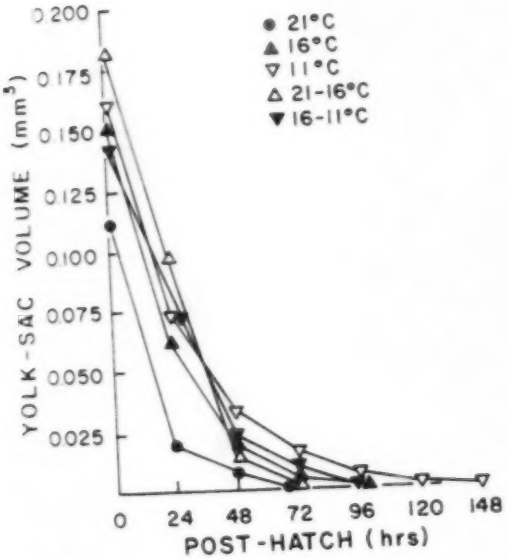

Fig 1. *Paralichthys dentatus*. Yolk utilization by larvae cultured under various constant and cyclic thermal regimes

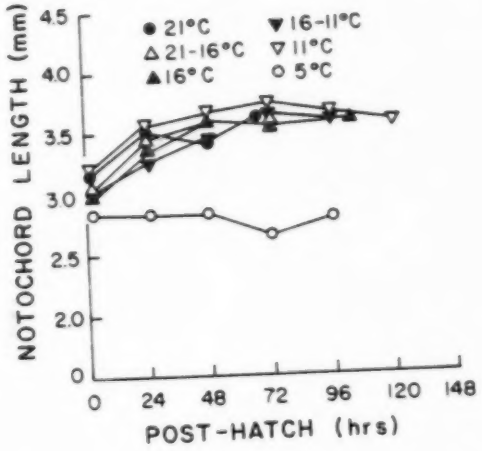

Fig. 2. *Paralichthys dentatus*. Growth of larvae cultured under various constant and cyclic thermal regimes

reserves decreased during larval development, the rate of utilization slowing prior to total depletion (Fig. 1). A similar pattern of yolk depletion is seen in larvae cultured in cyclic temperatures (Table 5; Fig. 1). Larvae maintained at 5 °C had abnormally shaped yolk-sacs that could not be measured. These larvae did not survive through complete yolk-sac absorption, and those at 11[2]-5 °C CYC died prior to hatching.

Incubation temperature had significant effect on the length of summer flounder larvae at hatching (Table 6). Yolk-sac larvae hatching at 11 °C CON were significantly larger ($P \leq 0.05$) than larvae in the other conditions, while those hatched at 5 °C CON were the smallest. There were no significant differences however in the notochord length of the surviving larvae at yolk-sac absorption (Table 6). Growth between hatching and yolk-sac absorption occurred in two phases (Tables 7 and 8; Fig. 2). Most growth in length occurred between 24 and 48 h after hatching. During the remainder of the yolk-sac period, little change in notochord length was noted. Larvae incubated at 5 °C did not increase in length after hatching.

Table 6. *Paralichthys dentatus*. Mean notochord length and dry weights (± 1 SD) of summer flounder larvae at hatching and after yolk-sac absorption. Means having the same grouping letter are not significantly different. (*n*): sample size

Temp regime (°C)	At hatch						At yolk-sac absorption					
	Length (mm)	(*n*)	Grouping	Ash-free dry weight (μg)	(*n*)	Grouping	Length	(*n*)	Grouping	Ash-free dry weight (μg)	(*n*)	Grouping
21	3.16 ± 0.17	46	B	11.0 ± 3.1	10	A	3.64 ± 0.12	50	A	23.1 ± 1.8	10	A
21–16	3.02 ± 0.16	50	C	7.4 ± 2.6	10	B	3.54 ± 0.24	50	A	21.4 ± 3.4	10	A
16	3.01 ± 0.16	49	C	13.4 ± 2.2	10	A	3.60 ± 0.17	42	A	22.4 ± 2.1	10	A
16–11	3.05 ± 0.11	48	C	14.9 ± 2.4	9	A	3.60 ± 0.13	50	A	21.0 ± 1.0	10	A
11	3.28 ± 0.23	51	A	13.7 ± 2.6	10	A	3.64 ± 0.14	50	A	22.9 ± 2.1	10	A
11–5	[a]											
5	2.83 ± 0.09	45	D				[a]					

[a] 100% mortality prior to this stage of development

Table 7. *Paralichthys dentatus*. Changes in notochord length and dry weight (mean ± 1 SD) during early development of larvae reared at various constant temperatures (*n*): sample size; •: yolk reserves exhausted, no further measurements taken

Temp (°C)	Post-hatch time (h)	Notochord length (mm)	(*n*)	Larval tissue dry-wt (μg)	(*n*)	% Ash	(*n*)	Larval tissue ash-free dry wt (μg)
21	0	3.16 ± 0.17	46	11.0 ± 3.1	10	13.5 ± 0.7	5	9.5
16	0	3.01 ± 0.16	49	13.4 ± 2.2	10	9.8 ± 0.6	5	12.1
11	0	3.28 ± 0.23	51	13.7 ± 2.6	10	9.7 ± 1.0	5	12.4
5	0	2.83 ± 0.09	45	[a]				
21	24	3.51 ± 0.13	49	23.9 ± 2.9	10	14.2 ± 0.9	5	20.5
16	24	3.38 ± 0.45	48	19.2 ± 2.4	10	11.3 ± 0.4	5	17.0
11	24	3.55 ± 0.23	56	19.5 ± 1.4	10	10.8 ± 0.8	5	17.4
5	24	2.81 ± 0.20	50	–				
21	48	3.41 ± 0.24	45	20.3 ± 2.3	7	16.7 ± 1.0	5	16.9
16	48	3.60 ± 0.17	49	20.3 ± 6.0	10	12.0 ± 1.3	5	17.9
11	48	3.65 ± 0.24	63	21.2 ± 1.5	10	12.4 ± 0.9	5	18.6
5	48	2.82 ± 0.30	38	–				
21	67	3.64 ± 0.12	50	23.2 ± 1.8	10	18.6 ± 1.5	5	18.8
16	72	3.55 ± 0.21	51	22.2 ± 2.1	10	15.2 ± 0.8	5	18.8
11	72	3.75 ± 0.27	65	21.3 ± 0.7	10	14.3 ± 1.9	5	18.3
5	72	2.64 ± 0.34	38	–				
21	•							
16	105	3.60 ± 0.17	42	22.4 ± 2.1	10	16.5 ± 1.2	5	18.7
11	96	3.70 ± 0.23	67	21.9 ± 1.1	10	14.8 ± 0.9	5	18.7
5	96	2.78 ± 0.33	25	–				
21								
16	•							
11	120	3.61 ± 0.17	51	23.5 ± 1.2	9	16.6 ± 1.5	5	19.6
5[b]								
21								
16								
11	137	3.64 ± 0.14	50	22.9 ± 2.1	10	16.0 ± 1.8	(5)	19.2

[a] Yolk-sac measurements unavailable; tissue weights of larvae cultured at 5 °C not calculated

[b] 100% mortality prior to total yolk-sac absorption

Table 8. *Paralichthys dentatus*. Changes in notochord length and dry weight (mean ± 1 SD) during early development of larvae reared at various cyclic temperatures. (*n*): sample size; *: yolk reserves exhausted, no further measurements taken

Temp cycle (°C)	Post-hatch time (h)	Notochord length (mm)	(*n*)	Larval tissue dry wt (μg)	(*n*)	% Ash	(*n*)	Larval tissue ash-free dry wt (μg)
21-16	0	3.02 ± 0.16	50	7.4 ± 2.6	10	10.5 ± 0.8	5	6.6
16-11	0	3.05 ± 0.11	48	14.9 ± 2.4	9	9.6 ± 0.6	5	13.5
11-5[a]								
21-16	24	3.48 ± 0.18	43	14.7 ± 2.3	10	12.8 ± 4.6	5	12.8
16-11	24	3.33 ± 0.16	49	19.9 ± 2.9	10	11.0 ± 0.5	5	17.7
21-16	48	3.58 ± 0.18	46	20.5 ± 1.0	10	15.2 ± 2.1	5	17.4
16-11	48	3.44 ± 0.17	50	22.3 ± 0.7	10	14.3 ± 1.9	5	19.1
21-16	72	3.54 ± 0.24	50	21.4 ± 3.4	10	16.7 ± 1.8	5	17.8
16-11	72	3.61 ± 0.14	45	19.5 ± 1.6	10	16.3 ± 0.9	5	16.3
21-16	*							
16-11	96	3.60 ± 0.13	50	21.0 ± 1.0	10	17.2 ± 1.5	5	17.4

[a] 100% mortality prior to this stage of development

Table 9. *Paralichthys dentatus*. Partitioning of yolk energy at 100% yolk utilization by summer flounder larvae incubated under various thermal regimes

Temp regime (°C)	C Initial energy content of egg (Yolk ash-free dry wt. × 0.223 J μg^{-1})[a]	P Energy converted to tissue (Larvae ash-free dry wt. × 0.0216 J μg^{-1})[a]	R + U Energy lost (C-P)	Yolk utilization efficiency (P/C × 100%)
21	0.643	0.406	0.237	63
21-16	0.643	0.384	0.259	60
16	0.643	0.404	0.239	63
16-11	0.643	0.376	0.267	58
11	0.643	0.415	0.228	65

[a] Values for energy content of ash-free yolk and larval tissue per unit weight are taken from Johns and Howell (1980)

Dry weights of larvae at hatching also were variable, larvae incubated at 21°-16°C CYC being significantly lighter than those maintained under the other thermal regimes (Table 6). At total yolk-sac absorption however, there were no significant differences in the dry weight of the larvae.

Larvae that survived to yolk-sac absorption utilized 0.643 J $larva^{-1}$ during development (Table 9). Of this, between 0.228 and 0.267 J $larva^{-1}$ were expended for catabolic requirements or excreted. The remaining energy was converted to tissue. The efficiency of this conversion varied between 58 and 65%. Differences in this efficiency reflect variances in the mean ash-free dry weight of the larvae. It should be noted that there were no significant differences in the dry weights of the larvae; therefore variations in yolk utilization efficiencies are not considered significant.

Discussion

Johns and Howell (1980) found the total length and ash-free dry weight of summer flounder larvae, at yolk-sac absorption, to be similar when cultured at 16° and 21°C. They concluded that summer flounder larvae were able to compensate physiologically for temperatures between 16° and 21°C with the ratio of the amount of yolk needed for total metabolism relative to the yolk converted to tissue remained constant. The present study extends these observations and indicates that summer flounder larvae exhibit developmental homeostasis by compensating for both constant and 5 C° cyclic temperatures throughout the zone of thermal tolerances. Notochord lengths and ashfree dry weights for all larvae, except those maintained in 5 °C CON and 11 °–5 °C CYC, were not significantly different at yolk-sac absorp-

tion. All larvae completing yolk-sac absorption exhibited pigmented eyes, functional mouths and complete digestive tracts prior to yolk exhaustion, indicating that they were capable of changing to exogenous sources of food.

In the 5 °C CON and 11 °-5 °C CYC thermal regimes, all larvae died prior to yolk-sac absorption. The lower zone of thermal resistance appears to be between 11 ° and 5 °C, and is probably closer to 5 °C, since larvae at 11 °C CON were able to complete yolk-sac development normally. The upper lethal limit was not found in this study, however summer flounder larvae have been successfully cultured in temperatures up to 24 °C (G. Laurence, personal communication). It appears that summer flounder embryos and larvae are eurythermal, surviving temperatures from near 5 ° to 24 °C. This is further indicated by field collections of Smith (1973) who found summer flounder eggs at mean water temperatures from 9.1 ° to 22.9 °C in continental shelf waters between Cape Cod, Massachusetts, and Cape Lookout, North Carolina, USA.

The cyclic regimes used in this study had little effect on the development of summer flounder embryos and larvae. Development times under each cyclic regime were intermediate to the development times at the temperature extremes of the cycle. The time both to hatching and to yolk-sac absorption were similar to what might be expected for the development of larvae at a constant temperature representing the mean of the thermal cycle. Growth rates as well as the size and weight of the larvae at yolk-sac absorption were also not affected by the 5 °C cyclic thermal regimes. Previous research concerning the effects of cyclic thermal regimes on various biological rates has indicated that the organism's response can show acceleration, reduction, or no change of rate relative to rates observed under constant temperatures (Lock and McLaren, 1970; McLaren, 1963; Sastry, 1976, 1979; Sastry and Ellington, 1978; Medvick, 1979). Results similar to those reported here for summer flounder larvae include experiments conducted on the development rates of crab larvae (Costlow and Bookhout, 1971; Sastry, 1976), growth in copepods (Lock and McLaren, 1970); crab larvae (Sastry, 1979), and juvenile fish (Medvick, 1979) and the bioenergetics of a bivalve (Widdows, 1976).

The maintenance of developmental homeostasis (*viz.* equal-sized larvae) in the face of thermal changes has been described for at least two other species of fish. Wood (1932) reported temperature independence in the efficiency with which yolk was converted to tissue in salmonid (*Salmo trutta*) embryos and larvae when cultured at 3 °, 7 °, 10 ° and 12 °C. The data for 10 °C were not Wood's original work but were calculated by him from the data of Gray (1926). Questions about thermal independence however were raised by Marr (1966) after recalculating Gray's data and finding that the yolk utilization efficiency at 10 °C was actually higher than that calculated by Wood. Nevertheless, in the present context it is significant that the larvae maintained at 3 °, 7 °, and 12 °C had the same yolk conversion efficiencies. Recently, Howell (1980) demonstrated thermal independence in larval size at yolk-sac absorption in yellowtail flounder (*Limanda ferruginea*) larvae cultured at 8 °, 10 ° and 12 °C. He found that both yolk utilization efficiency and notochord length of larvae at yolk-sac absorption under the various thermal regimes were not significantly different.

If the arguments regarding significance of larval size at yolk-sac absorption (Blaxter and Hempel, 1963; Blaxter, 1969) are correct then the fact that equal-sized larvae can result from widely different thermal regimes would indicate that survival to first feeding is not greatly different among summer flounder larvae throughout their temperature range. Therefore, summer flounder larvae produced throughout the spawning season would have the same advantages associated with being equal-sized. In addition, survival of larvae produced from one year to the next should also be similar since yearly differences in mean water temperature at spawning would have little effect on larval size at first feeding.

The ability to compensate physiologically for changes in temperature may also give summer flounder larvae a competitive advantage of first feeding over fish larvae that do not compensate for thermal changes. Once feeding commences, density-dependent biological interactions that could occur, such as competition for available food resources, predation and cannibalism, would play a more important role than physical factors in determining changes in year-class strength (Hunter, 1976). Such interactions may produce differential growth and survivorship among larvae, which could change the size structure and robustness of the 0-year class. Laurence *et al.* (1981) performed food competition experiments between larval cod (*Gadus morhau*) and haddock (*Melanogrammus aeglefinus*) and found that the cod larvae grew larger and survived better than did the haddock larvae. They concluded that the cod larvae were able to outcompete the haddock for available zooplankton food sources, and that they preyed on both haddock and other cod larvae. In the mid-Atlantic Bight, two other species of fish (Atlantic menhaden, *Brevoortia tyrannau* and window pane flounder, *Scophthalmus aquosus*) are present as part of the ichthyoplankton during the spawning and larval growth of the summer flounder (Kendall, 1975). It is possible that the types of competitive and predative interactions described by Laurence *et al.* (1981) could occur during larval development in the summer flounder; the outcome of such interactions could be important in the determination of year-class strength.

Acknowledgements. We wish to thank Drs. G. C. Laurence and J. Scott as well as Messrs. W. Berry, D. Bengtson, W. Nelson and A. Beck for their critical comments on various versions of the manuscript.

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Date of final manuscript acceptance: April 8, 1981.
Communicated by O. Kinne, Hamburg